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14. ABSTRACT
The explosive growth of Internet Media (partial-duplicate/similar images, 3D objects, 3D models, etc.) sheds bright light on many promising applications in forensics, surveillance, 3D animation, mobile visual search, and 3D model/object search. Compared with the general images, partial-duplicate images have some intrinsic properties such as high repeatability of local features, consistent local patch appearance, and stable spatial configuration. Compared with the general 2D objects, 3D models/objects consist of 3D data information (typically a list of vertices and faces) to represent 2D objects. However, these unique properties of partial-duplicate images and 2D

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ABSTRACT

The explosive growth of Internet Media (partial-duplicate/similar images, 3D objects, 3D models, etc.) sheds bright light on many promising applications in forensics, surveillance, 3D animation, mobile visual search, and 3D model/object search. Compared with the general images, partial-duplicate images have some intrinsic properties such as high repeatability of local features, consistent local patch appearance, and stable spatial configuration. Compared with the general 2D objects, 3D models/objects consist of 3D data information (typically a list of vertices and faces) to represent 3D objects. However, these unique properties of partial-duplicate images and 3D models have not been well exploited to design effective and efficient search algorithms. Because of this, existing works for large-scale partial-duplicate image retrieval and 3D model retrieval suffer from two major problems: low accuracy and low efficiency. These problems make them fall far below many applications' requirement. This project has investigated many key problems in large-scale partial-duplicate/similar image and 3D model retrieval: feature descriptor problem, image representation problem, index strategy problem, feature quantization problem, image search results quality assessment problem, image search reranking problem, sketch-based 3D model retrieval problem, and related search problems and has proposed a series of effective and efficient approaches to solve them.

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(a) Papers published in peer-reviewed journals (N/A for none)

Received	Paper
04/22/2016 96.00	Liang Zheng, Shengjin Wang, Peizhen Guo, Hanyue Liang, Qi Tian. Tensor index for large scale image retrieval, Multimedia Systems, (10 2014): 0. doi: 10.1007/s00530-014-0415-8
04/22/2016 09.00	Chunjie Zhang, Xiaobin Zhu, Liang Li, Yifan Zhang, Jing Liu, Qingming Huang, Qi Tian. Joint image representation and classification in random semantic spaces, Neurocomputing, (05 2015): 0. doi: 10.1016/j.neucom.2014.12.083
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Journal of Computer Science and Technology, (09 2014): 837. doi:

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Number of Papers published in peer-reviewed journals:

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Received Paper

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Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper
04/22/2016 07.00	Shanmin Pang, Jianru Xue, Zhanning Gao, Qi Tian. Image Re-ranking with an Alternating Optimization, the ACM International Conference. 02-NOV-14, Orlando, Florida, USA. : ,
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04/22/2016 11.00 Shanmin Pang, Jianru Xue, Nanning Zheng, Qi Tian. Locality preserving verification for image search,
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08/30/2012 5.00 Wengang Zhou, Meng Wang, Houqiang Li, Yijuan Lu, Qi Tian. Binary SIFT: Towards Efficient Feature Matching Verification for Image Search,
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08/31/2013 17.00 Shaomin Fang, Yijuan Lu, Xinmei Tian. Learning Image Saliency from Human Touch Behaviors,
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ACM Multimedia. 29-OCT-12, . : ,

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08/31/2013 18.00 Yijuan Lu, Ribel Fares, Bo Li. Semantic Sketch-based 3D Model Retrieval,
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08/31/2013 22.00 B. Li , Y. Lu, A. Godil, T. Schreck, M. Aono, H. Johan, J. M. Saavedra, S. Tashiro. SHREC'13 Track: Large Scale Sketch-Based 3D Shape Retrieval,
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08/31/2015 88.00 Liang Zheng, Shengjin Wang, Lu Tian, Fei He, Ziqiong Liu, Qi Tian. Query-Adaptive Late Fusion for Image Search and Person Re-identification,
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08/31/2015 89.00 Liang Zheng, Shengjin Wang, Lu Tian, Fei He, Ziqiong Liu, Qi Tian. Query-Adaptive Late Fusion for Image Search and Person Re-identification,
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08/31/2015 87.00 Bo Li, Yijuan Lu, Azeem Ghumman, Bradley Strylowski, Mario Gutierrez, Safiyah Sadiq, Scott Forster, Natacha Feola, Travis Bugerin. KinectSBR: A Kinect-Assisted 3D Sketch-Based3D Model Retrieval System,
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08/31/2015	83.00	Zhendong Mao, LingLing Tong, Hongtao Xie, Qi Tian. Hierarchical Encoding of Binary Descriptors for Image Matching, the 5th ACM. 22-JUN-15, Shanghai, China. : ,
08/31/2015	81.00	Dan Zeng, Yang Zhou, Shiliang Zhang, Qi Tian. Augmented Feature Fusion for Image Retrieval System, the 5th ACM. 22-JUN-15, Shanghai, China. : ,
08/31/2015	82.00	Sharath Pankanti, Qi Tian, Junjie Cai, Michele Merler. Heterogeneous Semantic Level Features Fusion for Action Recognition, the 5th ACM. 22-JUN-15, Shanghai, China. : ,
09/01/2014	23.00	R. Meruane, B. Bustos, T. Schreck, H. Johan, B. Li, Y. Lu, I. Sipiran. SHREC'13 Track: Large-Scale Partial Shape Retrieval Track Using Simulated Range Images, The 6th Eurographics Workshop on 3D Object Retrieval . 11-MAY-13, . : ,
09/01/2014	54.00	Bo Li, Y. V. Venkatesh, Ashraf Kassim, Yijuan Lu. Improving PMVS Algorithm For 3D SceneReconstruction from Sparse Stereo Pairs, Pacific-rim Conference on Multimedia. 13-DEC-13, . : ,
09/01/2014	55.00	Peng Zhao , Yijuan Lu , WenBin Wang , WeiWei Zhu. Automatic Image Annotation using Semantic Relevance, [2] International Conference on Internet Multimedia Computing and Service. 17-AUG-13, . : ,
09/01/2014	56.00	B. Li, Y. Lu, C. Li, A. Godil, T. Schreck, M. Aono, M. Burtscher, H. Fu, T. Furuya, H. Johan, J. Liu, R. Ohbuchi, A. Tatsuma, C. Zou. SHREC'14 Track: Extended Large Scale Sketch-Based 3DShape Retrieval, Eurographics Workshop on 3D Object Retrieval 2014. 06-APR-14, . : ,
09/01/2014	57.00	B. Li, Y. Lu, C. Li, A. Godil, T. Schreck, M. Aono, Q. Chen, N.K. Chowdhury, B. Fang, T. Furuya, H. Johan, R. Kosaka, H. Koyanagi, R. Ohbuchi, A. Tatsuma. SHREC'14 Track: Large Scale Comprehensive3D Shape Retrieval, Eurographics Workshop on 3D Object Retrieval 2014. 06-APR-14, . : ,
09/01/2014	58.00	X. Sun, P. L. Rosin, R. R. Martin, Z. Cheng, Z. Lian, D. Pickup, M. Aono, A. Ben Hamza, A. Bronstein, M. Bronstein, S. Bu, U. Castellani, S. Cheng, V. Garro, A. Giachetti, A. Godil, J. Han, H. Johan, L. Lai, B. Li, C. Li, H. Li, R. Litman, X. Liu, Z. Liu, Y. Lu, A. Tatsuma, J. Ye. SHREC'14 Track:Shape Retrieval of Non-Rigid 3D Human Models, Eurographics Workshop on 3D Object Retrieval 2014. 06-APR-14, . : ,
09/01/2014	59.00	Bingbing Ni, Yang Zhou, Shuicheng Yan, Pierre Moulin, Qi Tian. Pipelining Localized Semantic Features for Fine-Grained Action Recognition, European Conference on Computer Vision. 16-SEP-14, . : ,
09/01/2014	60.00	Lingxi Xie, Qi Tian, Bo Zhang. Max-SIFT: Flipping Invariant Descriptors for Web Logo Search, IEEE International Conference on Image Processing. 27-OCT-14, . : ,

09/01/2014 61.00 Liang Zheng, Shengjin Wang, Wengang Zhou, Qi Tian. Bayes Merging of Multiple Vocabularies for Scalable Image Retrieval,
IEEE International Conference on Computer Vision and Pattern Recognition. 17-JUN-14, . : ,

09/01/2014 62.00 Liang Zheng, Shengjin Wang, Ziqiong Liu, Qi Tian. Packing and Padding: Coupled Multi-index for Accurate Image Retrieval,
IEEE International Conference on Computer Vision and Pattern Recognition. 17-JUN-14, . : ,

09/01/2014 63.00 Lingxi Xie, Jingdong Wang, Baining Guo, Bo Zhang, Qi Tian. Orientational Pyramid Matching for Recognizing Indoor Scenes,
IEEE International Conference on Computer Vision and Pattern Recognition. 17-JUN-14, . : ,

09/01/2014 64.00 Zhenxing Niu, Gang Hua, Xinbo Gao, Qi Tian. Semi-supervised Relational Topic Model for Weakly Annotated Image Recognition in Social Media,
IEEE International Conference on Computer Vision and Pattern Recognition. 17-JUN-14, . : ,

09/01/2014 65.00 Junjie Cai, Qiong Liu, Francine Chen, Dhiraj Joshi, Qi Tian. Scalable Image Search with Multiple Index Tables,
ACM International Conference on Multimedia Retrieval. 01-APR-14, . : ,

09/01/2014 66.00 Shiliang Zhang, Ming Yang, Xiaoyu Wang, Yuanqing Lin, Qi Tian. Semantic-aware Co-indexing for Near-Duplicate Image Retrieval,
International Conference on Computer Vision. 03-DEC-13, . : ,

09/01/2014 67.00 Lingxi Xie, Qi Tian, Richang Hong, Shuicheng Yan, Bo Zhang. Hierarchical Part Matching for Fine-Grained Visual Categorization,
International Conference on Computer Vision. 03-DEC-14, . : ,

09/01/2014 68.00 Zhendong Mao, Yongdong Zhang, Qi Tian. A Novel Feature Descriptor Exploring Anisotropy and Non-uniformity,
Pacific-rim Conference on Multimedia. 13-DEC-13, . : ,

TOTAL: 67

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received		Paper
08/30/2012	2.00	Xinmei Tian, Yijuan Lu. Discriminative Codebook Learning for Web Image Search, Signal Processing (04 2012)
08/30/2012	4.00	Wengang Zhou, Houqiang Li, Yijuan Lu, Qi Tian. Principal Visual Word Discovery for AutomaticLicense Plate Detection, Transactions on Image Processing (04 2012)
08/30/2012	3.00	Wengang Zhou, Houqiang Li, Yijuan Lu, Qi Tian. SIFT Match Verification by Geometric Coding for Large Scale Partial-duplicate Web Image Search, ACM Transactions on Multimedia Computing, Communications and Applications (01 2012)
08/31/2015	94.00	D. Pickup, X. Sun, P. L. Rosin, R. R. Martin, Z. Cheng, Z. Lian, M. Aono, A. Ben Hamza, A. Bronstein, M. Bronstein, S. Bu, U. Castellani, S. Cheng, V. Garro , A. Giachetti, A. Godil, L. Isaia , J. Han · H. Johan · L. Lai · B. Li · C. Li · H. Li · R. Litman · X., Liu · Z. Liu · Y. Lu · G. Tam · A. Tatsuma · J. Ye ·. Shape Retrieval of Non-Rigid 3D Human Models, International Journal of Computer Vision (09 2014)
08/31/2015	93.00	Bo Li, Yijuan Lu, Henry Johan, Ribel Fares. Sketch-based 3D model retrieval utilizing adaptive view clustering and semantic information, Computer Vision and Image Understanding (05 2015)
08/31/2015	92.00	Bo Li, Henry Johan, Yuxiang Ye, Yijuan Lu. Efficient 3D Reflection Symmetry Detection: a View-Based Approach, Graphical Models (03 2015)
09/01/2014	51.00	Xinmei Tian, Linjun Yang, Yijuan Lu, Qi Tian. Topic-aware Image Search Reranking, IEEE TRANSACTIONS ON Systems, Man, Cybernetics (11 2012)
09/01/2014	50.00	Bo Li, Yijuan Lu, Henry Johan, Ribel Fares. Sketch-based 3D model retrieval utilizing adaptive viewclustering and semantic information, Pattern Recognition (05 2014)
09/01/2014	52.00	Wengang Zhou, Houqiang Li, Yijuan Lu, Qi Tian. BSIFT: towards Data-Independent Codebook forLarge Scale Image Search, IEEE TRANSACTIONS ON Image Processing (09 2013)
09/01/2014	53.00	Bo Li, Yijuan Lu, Chunyuan Li, Afzal Godil, Tobias Schreck, Masaki Aono, Martin Burtscher, Qiang Chen, Nihad Karim Chowdhury, Bin Fang, Hongbo Fu, Takahiko Furuya, Haisheng Li, Jianzhuang Liu, Henry Johan, Ryuichi Kosaka, Hitoshi Koyanagi, Ryutarou Ohbuchi, Atsushi Tatsuma, Yajuan Wan, Chaoli Zhang, Changqing Zou. A comparison of 3D shape retrieval methods based on a large-scale benchmark supportingmultimodal queries, Computer Vision and Image Understanding (06 2014)

TOTAL: **10**

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Award:
This project has resulted in the following¬¬ prestigious awards:

- Best Paper Award, the 4th ACM International Conference on Internet Multimedia Computing and Service (ICIMCS 2I012), September 2012.
- Best Paper Award, the IEEE International Conference on Multimedia and Expo (ICME) 2013.
- Best Paper Award, the Pacific-rim Conference on Multimedia (PCM), 2013.
- Best Paper Award, the 19th International Conference on Multimedia Modeling (MMM), January 2013.
- Best Paper Award, the ACM International Conference on Multimedia Retrieval (ICMR), June, 2015.
- Best Student Paper Candidate, the IEEE International Conference on Multimedia and Expo (ICME), July 28-July 2, 2015.

Honor and Recognition:
Faculty:

- Dr. Yijuan Lu (PI) was awarded Texas State University Junior Faculty Research Enhancement Award 2012.
- Dr. Yijuan Lu (PI) was nominated to Texas State University Presidential Award For Excellence In Scholarly/Creative Activities 2012.
- Dr. Qi Tian (co-PI) was promoted to Full Professor at UTSA, December 2012.
- Dr. Yijuan Lu (PI) and her team won the First Place in "Large Scale Sketch-Based 3D Shape Retrieval Competition", First Place in "Large-Scale Partial Shape Retrieval Using Simulated Range Images Competition", and Second Place in "Retrieval of Objects Captured with Low-Cost Depth-Sensing Cameras Competition" in EUROGRAPHICS 3D Shape Retrieval Contest 2013 (SHREC'13)
- Dr. Yijuan Lu (PI) is nominated to Texas State University Presidential Award For Excellence In Scholarly/Creative Activities 2013.
- Dr. Yijuan Lu (PI) received College Achievement Award for the Presidential Award for Excellence in Scholarly/Creative Activities, College of Science and Engineering, Texas State University, 2014.
- Dr. Qi Tian (co-PI) received Research Achievement Award, College of Science, UTSA, December 2014.
- Dr. Yijuan Lu (PI) received Presidential Distinction Award for Excellence in Service, Texas State University, 2015.
- Dr. Yijuan Lu (PI) and her team won the First Place in "3D Sketch-Based 3D Shape Retrieval Competition" in EUROGRAPHICS 3D Shape Retrieval Contest 2016 (SHREC'16).
- Dr. Qi Tian (co-PI) is elevated to IEEE Fellow (class 2016), November 2015.

Student:

- Shaomin Fang received Excellence in Graduate Research Award at Texas State University 2013.
- Yuxiang Ye received Excellence in Graduate Research Award at Texas State University 2014, 2015.
- Junjie Cai received ACM Multimedia Student Travel Award 2014.
- Junjie Cai received UTSA Graduate Student Professional Development Award 2014.

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Shaomin Fang	0.50	
Travis Bulgerin	0.10	
Yuxiang Ye	0.50	
jie Xiao	0.08	
Junjie Cai	1.00	
Xia Li	0.08	
Yang Zhou	0.02	
FTE Equivalent:	**2.28**	
Total Number:	**7**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Xinmei Tian	0.10
Wengang Zhou	0.10
Bo Li	1.00
FTE Equivalent:	**1.20**
Total Number:	**3**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Yijuan Lu	0.08	No
Qi Tian	0.08	No
FTE Equivalent:	**0.16**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Daniel Brooks	0.08	Computer and Computational Sciences
Robert Dunk	0.08	Computer and Computational Sciences
FTE Equivalent:	**0.16**	
Total Number:	**2**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 2.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 2.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 2.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:..... 0.00

Names of Personnel receiving masters degrees

NAME
Shaomin Fang
Travis Bulgerin
Yuxiang Ye
Total Number: **3**

Names of personnel receiving PHDs

NAME
xia Li
Jie Xiao
junjie Cai
Total Number: **3**

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

1) Foreword

This project started in January 2012 and ended in January 2016 with one year no-cost extension from January 2015 to January 2016. There are three Post-docs (Xinmei Tian, Wengang Zhou, Bo Li), three Ph.D. students (Jie Xiao, 2008-2014, Xia Li, 2008-2014, Junjie Cai, 2011-2015, Yang Zhou, 2015), and two master students (Shaomin Fang, 2012-2013, Yuxiang Ye, 2014-2016) supported by this ARO grant. Xinmei Tian and Wengang Zhou joined CS Department of University of Science and Technology of China as tenure-track assistant professors. Bo Li joined Department of Mathematics and Computer Science in University of Central Missouri as an assistant professor in 2015. Xia Li joined in Google in 2014 as a Software Development Engineer (SDE). Jie Xiao joined in Rocket Fuel Inc. as a Research Scientist in 2014. Junjie Cai joined in Blippar Inc. as a Research Scientist in 2015. Shaomin Fang joined in Emerson at Austin in 2013 and Yuxiang Ye will graduate in May 2016 and will join in Google June 2016. The project has been finished successfully within the timeline and all the research goals proposed in the original proposal have been achieved.

During the project period, the PI Dr. Lu was promoted to Associate Professor at Texas State. Dr. Tian was promoted to Full Professor at UTSA and was elevated to IEEE Fellow (class 2016). The PIs sincerely thank for ARO and the program manager Dr. Liyi Dai for supporting this research during the past 4 years. Without the dedicated support from Dr. Dai and ARO, this project won't be done successfully. We look forwards to the future research collaboration with Dr. Dai and ARO.

2. Statement of the problem studied

The explosive growth of Internet Media (partial-duplicate/similar images, 3D objects, 3D models, etc.) sheds bright light on many promising applications in forensics, surveillance, 3D animation, mobile visual search, and 3D model/object search. Compared with the general images, partial-duplicate images have some intrinsic properties such as high repeatability of local features, consistent local patch appearance, and stable spatial configuration. Compared with the general 2D objects, 3D models/objects consist of 3D data information (typically a list of vertices and faces) to represent 3D objects. However, these unique properties of partial-duplicate images and 3D models have not been well exploited to design effective and efficient search algorithms. Because of this, existing works for large-scale partial-duplicate image retrieval and 3D model retrieval suffer from two major problems: low accuracy and low efficiency. These problems make them fall far below many applications' requirement. This project has investigated many key problems in large-scale partial-duplicate/similar image and 3D model retrieval: feature descriptor problem, image representation problem, index strategy problem, feature quantization problem, image search results quality assessment problem, image search reranking problem, sketch-based 3D model retrieval problem, and related search problems and has proposed a series of effective and efficient approaches to solve them.

3. Summary of the scientific accomplishments

The key elements developed in this project will make significant contributions to improve the performance of large scale partial duplicate image retrieval system, large scale 3D model retrieval system, and personalized image retrieval. The research teams are one of the first (to their best knowledge) in the field who

- propose a novel strategy to generate a reliable, easily updated visual dictionary with low computational cost. In our method, no visual codebook is needed to be trained and the quantizer is independent of collections of images;
- propose to formulate the codebook construction and contextual subspace learning into one optimization problem and embed semantic information;
- apply visual word expansion approach to reduce the feature quantization error and boost the retrieval recall;
- propose to embed the spatial information between local features into the inverted index file efficiently;
- propose to build geometric square coding and geometric fan coding together to fully capture the global geometric context of local features in an image and effectively discover false feature matches between images.
- propose a novel flexible scale invariant feature transform (SIFT) binarization (FSB) algorithm;
- propose to explore the use of partial binary descriptors as direct codebook indices (addresses);
- introduce a novel IDF family by the use of Lp-norm pooling technique;
- propose a novel attribute-assisted retrieval model for reranking images;
- build the largest comprehensive 3D shape database that contains different types of models including generic, articulated, CAD and architecture models;
- construct the largest sketch-3D model benchmark that contains a large number of diverse types of sketches and models;
- apply, compare, and analyze state-of-the-art 3D model retrieval approaches on the collected sketch and 3D model benchmark;
- propose a simple and efficient view-based 3D symmetry detection method.
- propose a novel matching verification scheme based on binary SIFT (BSIFT);
- propose two novel binary feature descriptors: COGE and Edge-SIFT and investigate representing the spatial context of local features into binary codes;
- encode local invariant features and high level semantic attributes together to effectively enhance the discriminative capability of inverted indexes;
- use the semantic classification information to reduce the semantic gap, as well as to adequately utilize the better-performing global feature matching to improve sketch-based 3D model retrieval efficiency;
- propose a 3D visual complexity metric based on the viewpoint entropy distribution of a set of sample views;
- explore the correlations between users' different touch behaviors and human attention, investigate their contribution to the human eye fixation, and propose a novel supervised learning approach to learn good image saliency maps from multiple touch

behaviors.
During the past year (2012), the following scientific accomplishments have been made:
1) Scalar Quantization
The research team investigate bit vector quantization algorithms to address the “high computational cost”, “limited reliability”, and “update inefficiency” problems in the codebook generation stage. A novel feature quantization algorithm, scalar quantization, is proposed. With scalar quantization, a local feature is quantized to a descriptive and discriminative bit-vector, of which the first tens of bits are taken out as code word. Our quantizer is independent of collections of images. In addition, the result of scalar quantization naturally lends itself to adapt to the classic inverted file structure for image indexing. Moreover, the quantization error can be flexibly reduced and controlled by efficiently enumerating nearest neighbors of code words.
2) Discriminative Codebook Learning
The research team propose a novel supervised discriminative codebook learning method, which can find a contextual subspace to embed the semantic information into codebook generation and learn a contextual subspace and discriminative codebook simultaneously. In the learned new space, images from different classes can be well separated and images from the same class are close to each other. The research team applied the proposed method on Web image search re-ranking problem and the experimental results on two real Web image search datasets have demonstrated the effectiveness of our approach and its superiority than other state-of-the-art codebook learning methods.
3) Visual Word Expansion and Binary SIFT
The research team propose a novel visual word expansion approach to improve the feature quantization accuracy and boost the retrieval recall. The proposed visual word expansion scheme is based on the observation that the expected nearest visual word to a test feature is always close to the approximate nearest visual word, which can be efficiently identified by the hierarchical k-NN search. Experiments on image search in million-scale dataset demonstrate the effectiveness of the proposed visual word expansion approach.
Moreover, the research team design a new scheme to transform a SIFT descriptor to a binary bit stream, called binary SIFT. Extensive study with large-scale (trillion) samples reveal that the generated binary SIFT effectively keeps the distance metric of the original SIFT descriptor.
4) Embedding Spatial Context into Inverted File
The research team explore two novel ways to embed the spatial information between local features into the inverted index file. A one-one relationship approach is proposed to record feature tuples into the inverted file, which consist of a pair of single features and their corresponding spatial relationship. A one-multiple relationship approach is proposed to record the spatial relationship between a single feature and its surrounding features, which are clustered into different groups based on their locations. With the embedded spatial information in the inverted index file, feature matching with geometric verification can be performed implicitly, efficiently, and effectively in the inverted file traversing step, which make the proposed methods more suitable for large-scale image search.
5) Spatial and Geometric Coding for Geometric Verification
The research team investigate two different coding algorithms “Spatial Coding” and “Geometric Coding” to achieve fast and accurate geometric verification of local features in the post processing step. The proposed spatial coding algorithm encodes the relative positions between each pair of features along the horizontal (X-axis) and vertical (Y-axis) direction by generating two binary spatial maps X-map and Y-map. The proposed geometric coding method consists of geometric square coding and geometric fan coding, which describe the spatial relationships of local features (e.g. inside or outside of geometric square and fan) into H-map, V-map, and S-map for global verification to remove geometrically inconsistent feature matches. These two approaches are not only computationally efficient, but also effective in detecting partial-duplicate images with rotation, scale changes, partial-occlusion, and background clutter.
6) Applications
During the exploration of solutions to solve the above scientific barriers in the partial duplicate image retrieval, the research team find some other interesting applications, which may share similar problems, such as license plate detection (characters in different license plates are duplicates of each other), similar song retrieval, and 3D image search. Motivated by these similarities, several new approaches are proposed for these applications by bringing the ideas in the partial duplication image retrieval.
Observing that characters in different license plates are duplicates of each other, we bring in the idea of bag-of-words (BoW) model popularly into license plate detection. The research team propose a novel scheme to automatically locate license plate by principal visual word discovery and local feature matching. For large scale similar song retrieval, the research team proposed to utilize beat-aligned chroma patches and applied location coding scheme to encode the location relationships among beat-aligned chroma patches in a song. Our approach is both efficient and effective to discover true matches of beat chroma patches between songs with low computational cost. In the 3D image retrieval, the research team propose a sketch-based 3D model retrieval algorithm by utilizing viewpoint entropy-based adaptive view clustering and shape context matching. The algorithm is tested on a latest sketch-based 3D model retrieval benchmark and the results demonstrate the superior performances and advantages of our algorithm.
During the past year (2013), the following scientific accomplishments have been made:
7) Feature Quantization
The research team propose to construct a supporting visual word table for all visual words by visual word expansion. Given the initial quantization result, multiple approximate nearest visual words are identified by checking supporting visual word table, which benefits the retrieval recall. Moreover, a matching verification scheme based on binary SIFT (BSIFT) is presented. The L2-distance between original SIFT descriptors is demonstrated to be well kept with the metric of Hamming distance betThe

research teamen the corresponding binary SIFT vectors. With the BSIFT verification, false positive matches can be effectively and efficiently identified and removed, which greatly improves the accuracy of large-scale image search. The proposed approach is evaluated by conducting partial-duplicate image search on a one-million image database. The experimental results demonstrate the effectiveness and efficiency of the proposed scheme.

8) Binary Feature Descriptors for Image Retrieval

The research team propose two novel binary feature descriptors: COGE and Edge-SIFT. The proposed COGE exploits the anisotropy and the non-uniformity of the underlying gradient distributions. Therefore, it exhibits better results than state-of-the-art methods with respect to distinctiveness, robustness, and storage cost. The proposed Edge-SIFT is generated from the binary edge maps of scale and orientation-normalized image patches. By preserving both locations and orientations of edges and compressing the sparse binary edge maps with a boosting strategy, Edge-SIFT shows strong discriminative power with compact representation.

In addition, the research team investigate representing the spatial context of local features into binary codes to implicitly achieve geometric verification by efficient comparison of the binary codes. Moreover, a weighted Hamming distance ranking algorithm (WhRank) to rank the binary codes of hashing methods is developed. By assigning different bit-level weights to different hash bits, the returned binary codes are ranked at a finer-grained binary code level. Experiments on several state-of-the-art benchmark data sets with million-scale distractor images demonstrate the effectiveness of the proposed algorithms.

9) Semantic-aware Co-indexing for Image Search

The research team propose a novel approach for embedding semantic attributes into the pipeline of image search. Inverted indexes in image retrieval not only allow fast access to database images but also summarize all knowledge about the database, so that their discriminative capacity largely determines the retrieval performance. For vocabulary tree based image retrieval, a semantic-aware co-indexing algorithm is proposed to jointly embed two strong cues into the inverted indexes: 1) local invariant features that are robust to delineate low-level image contents, and 2) semantic attributes from large-scale object recognition that may reveal image semantic meanings. Encoding these two distinct cues together effectively enhances the discriminative capability of inverted indexes. Such co-indexing operations are totally off-line, and therefore introduce small computation overhead to online query. Experiments and comparisons with recent retrieval methods have evidently demonstrated the significant improvement in retrieval performance and efficiency.

10) Sketch-based Image/3D Model Retrieval

The research team propose a new sketch feature to capture both the local and global information of a sketch. The proposed sketch feature can handle the rotation of sketches better by further integrating a set of rotation-invariant global features for a sketch. In addition, an intelligent sketch recognizer through supervised learning is developed to correctly capture the semantic meanings of users' sketches. The research team also conducts a comprehensive study of the semantic gap between user sketches and 3D models and proposes a novel semantic sketch-based 3D model search algorithm to bridge such a semantic gap. The experimental results confirmed that the proposed sketch recognizer is more robust to sketch rotation and can describe user sketches well. In addition, the proposed semantic retrieval approach significantly improves the retrieval accuracy and reduces the search time over other state-of-the-art sketch-based 3D model retrieval algorithms. It further validated that the proposed approach could bridge the semantic gap between the diverse query sketches and 3D models effectively.

11) Large Scale 3D Model Retrieval

The research team propose a new 3D model retrieval algorithm by adaptive view clustering. A novel 3D visual complexity metric is formulated based on the viewpoint entropy distribution of a set of uniformly sampled views of the 3D model. Then, it guides adaptive view clustering of a 3D model to shortlist a set of representative sample views for 2D-3D comparison, which largely reduces the number of sample views for comparison and therefore greatly improves the computational efficiency. After that, a shape context matching algorithm is used for the 2D-3D matching between the query and the representative views for each model. Experimental results on several latest benchmarks have evidently demonstrated our significant improvement in retrieval performance and efficiency.

In addition, the research team organize a "Large Scale Sketch-based 3D Model Retrieval" competition in the Shape Retrieval Contest (SHREC) 2013, which is held at the 3D Object Retrieval (3DOR) workshop of Eurographics 2013. In the meantime, the research team also attend two SHREC contests on "Large-Scale 3D Partial Shape Retrieval Track Using Simulated Range Images" and "Retrieval of 3D Objects Captured with Low-Cost Depth-Sensing Cameras". In these competitions, the proposed 3D model retrieval algorithm receives First Place in the large-scale sketch-based 3D retrieval track, First Place in the range scan track, and obtains Second Place in the low-cost depth-sensing camera track.

12) Touch-based Personalized Image Search

The research team quantitatively studied and analyzed human attention from a variety of touch behaviors, and proposes a set of valuable features from the touch information. A series of experiments are designed and conducted with the conventional eye-fixation based saliency serving as the ground truth. An image browsing app is designed on a touch mobile phone to collect users' touch behavior data. In addition, a novel touch saliency learning approach is proposed to automatically learn the correlation between different touch behaviors and human eye fixations, and then to derive a good image saliency map from a variety of touch behaviors. During the process of building a supervised learning model, the weights of different human touch behaviors are learned, which indicate the different contributions of these behaviors to the user's attention information. The experimental results have demonstrated the validity of the study and the potential and effectiveness of the proposed approach.

13) Applications

In addition, the research team explored many important related problems: 1) "human movement summarization and depiction from videos" problem. Previous action summarization methods all rely on 3D motion capture or manually labeled data, without which depicting actions is a challenging task. A novel scheme is proposed to automatically summarize and depict human

movements from 2D videos without 3D motion capture or manually labeled data. The proposed method can successfully segment videos into sub-actions with an effective streamline matching scheme, track points on body parts, and depict the human articulated motion with arrows and motion particles. 2) “image matching” problem. A new matching method, Semantic-Spatial Matching (SSM) is proposed. SSM conducts region matching by considering both the spatial layout and the semantic content information. SSM has the advantage not only being robust to rotation, flipping and other variances, but also simple and easy for implementation. Experiments on two benchmark datasets demonstrate its effectiveness in object and scene classifications. 3) “3D scene reconstruction” problem. The performance of the PMVS (Patch-based Multi-View Stereo software) for scene reconstruction from stereo pairs of scenes captured by a simple 3D camera has been analyzed. A Canny feature-based PMVS algorithm and a preliminary disparity map-based stereo reconstruction algorithm are proposed. Both proposed approaches are promising for related applications which require effective 3D scene reconstruction from a set of sparsely sampled pairs. 4) “image annotation” problem. An automatic image annotation approach using semantic relevance is proposed. It constructs an improved probabilistic model to characterize different regions’ contributions to the semantics more accurately based on the spatial，visual and contextual information of the region. And it also helps expand the coverage of the semantic concept with semantic relevance information.

During the past year (2014), the following scientific accomplishments have been made:

14) Compact Binary Feature Descriptors for Image Retrieval

The research team propose a novel flexible scale invariant feature transform (SIFT) binarization (FSB) algorithm for large-scale image search. The FSB algorithm explores the magnitude patterns of SIFT descriptor. It is unsupervised and the generated binary codes are demonstrated to be dispreserving. Besides, a new searching strategy is investigated to find target features based on the cross-indexing in the binary SIFT space and original SIFT space. The experiments on large-scale partial duplicate image retrieval system demonstrate the effectiveness and efficiency of the proposed algorithm.

In addition, the research team explored the use of partial binary descriptors as direct codebook indices (addresses). Typically, binary descriptors are clustered into codewords and quantized with Hamming distance, following the conventional bag-of-words strategy. However, such codewords formulated in Hamming space do not present obvious indexing and search performance improvement as compared to the Euclidean codewords. Without explicit codeword construction, the proposed approach performs to build multiple index tables which concurrently check for collision of the same hash values. The evaluation is performed on two public image datasets and the experimental results demonstrate the indexing efficiency and retrieval accuracy of our approach.

15) TF-IDF strategy for Image Retrieval

The research team introduced a novel IDF family by the use of Lp-norm pooling technique. Carefully designed, the proposed IDF considers the term frequency, document frequency, the complexity of images, as well as the codebook information. The research team further proposes a parameter tuning strategy, which helps to produce optimal balancing between TF and pIDF weights, yielding the so-called Lp-norm IDF (pIDF). Further, by counting for the term-frequency in each image, the proposed pIDF helps to alleviate the visual word burstiness phenomenon.

Moreover, the team initializes to embed multiple binary features at indexing level. To model correlation between features, a multi-IDF scheme is introduced, through which different binary features are coupled into the inverted file. As an extension, the research team also explores the fusion of binary color feature into image retrieval. The joint integration of the SIFT visual word and binary features greatly enhances the precision of visual matching, reducing the impact of false positive matches.

16) An attribute-assisted Reranking Model for Web Image Search

The research team proposed a novel attribute-assisted retrieval model for reranking images. Based on the classifiers for all the predefined attributes, each image is represented by an attribute feature consisting of the responses from these classifiers. A hypergraph is used to model the relationship between images by integrating low-level visual features and semantic attribute features. And hypergraph ranking is applied to re-order the images. Its basic principle is that visually similar images should have similar ranking scores. A visual-attribute joint hypergraph learning approach has been proposed to simultaneously explore two information sources. The extensive experiments have been conducted on 1,000 queries in MSRA-MM V2.0 dataset. The experimental results demonstrate the effectiveness of the proposed attribute-assisted Web image search reranking method.

17) Large Scale Comprehensive 3D Model Retrieval

The research team built a Large Scale Comprehensive 3D model Benchmark dataset (SHREC14LSGTB). This 3D shape dataset contains 8,987 models in a variety of types (generic, articulated, CAD and architecture models) and classified into 171 categories. This work is the first work to integrate existing 3D model datasets to form a new, larger benchmark corpus for comprehensive 3D shape retrieval. The newly created benchmark is the most extensive to date in terms of the number of semantic query categories covered as well as the variations of model types. In particular, it combines generic and domain dependent model types and therefore rates the retrieval performance with respect to cross-domain retrieval tasks.

18) Sketch-based 3D Model Retrieval

The research team built the largest sketch-3D model benchmark dataset. The benchmark contains 13,680 sketches and 8,987 3D models, divided into 171 distinct classes. The developed benchmark is the most extensive to date in terms of the number of semantic query categories covered as well as the variations of model types. The benchmark supports both sketch and 3D model queries, thus providing a unified platform to test diverse 3D model retrieval algorithms belonging to either Query-by-Model or Query-by-Sketch 3D retrieval techniques. This benchmark also provides an important resource for the community of sketch-based 3D retrieval and will foster the development of practical sketch based 3D retrieval applications.

Based on this new developed benchmark, the research team organized a sketch-based 3D model retrieval contest in 2014 Eurographics. The task of the contest is to evaluate the performance of different sketch-based 3D model retrieval algorithms

using a large scale hand-drawn sketch query dataset on a comprehensive 3D model dataset. 12 runs of 6 methods have been submitted by 4 groups. The research team performs a comprehensive comparison study and evaluates current state-of-the-art sketch-based retrieval approaches, especially in terms of scalability using 7 popular performance metrics. This benchmark and comprehensive study will provide important guidance on future research directions of this research area.

19) 3D Symmetry Detection

The research team proposed a novel and efficient view-based symmetry detection algorithm. The proposed algorithm can find symmetry plane(s) by matching the viewpoint entropy features of a set of sample views of a 3D model aligned beforehand using Continuous Principal Component Analysis (CPCA). The experimental results show the proposed symmetry detection algorithm is more accurate (in terms of both the positions of detected symmetry planes and sensitivity to minor symmetry differences), efficient, robust (e.g. to the number of vertices and parameter settings such as view sampling), and versatile in finding symmetry planes of diverse models.

During the past year (2015), the following scientific accomplishments have been made:

20) Feature Descriptors for Large-scale Image Retrieval

The research team propose a novel cascaded scalar quantization scheme in dual resolution. They formulate the visual feature matching as a range-based neighbor search problem and approach it by identifying hyper-cubes with a dual-resolution scalar quantization strategy. Specifically, for each dimension of the dimension-reduced feature, scalar quantization is performed at both coarse and fine resolutions. The scalar quantization results at the coarse resolution are cascaded over multiple dimensions to index an image database. The scalar quantization results over multiple dimensions at the fine resolution are concatenated into a binary super-vector and stored into the index list for efficient verification. The proposed cascaded scalar quantization (CSQ) method is free of the costly visual codebook training and thus is independent of any image descriptor training set. The index structure of the CSQ is flexible enough to accommodate new image features and scalable to index large-scale image database.

The research teams also extend the concept of image retargeting and propose a new image resizing approach that is devoted to preserving the robust local features in the query image while resizing it. Based on the extended concept, a novel mobile-visual-search scheme is introduced to conduct the proposed approach to reduce the size of the query image for achieving low bit-rate visual search. Extensive experiments show that the proposed approach obtains superior retrieval performance than state-of-the-art image resizing approaches at the similar query size; meanwhile, it is cost effective in terms of processing time.

21) Image Representation for Large-scale Image Retrieval

The research team propose a hierarchical method to construct VLAD descriptor (HVLAD) to inherit the benefit of finer division bringing by larger vocabulary while preserving the same dimension with the original VLAD descriptor. In the proposed HVLAD descriptor, by generating sub-words to each words of the coarse vocabulary that is adopted to build original VLAD descriptor, a hidden layer visual vocabulary is constructed. With the hidden layer vocabulary, the feature space is finely divided. The residual vectors between local features and sub-words are first aggregated at the hidden layer and then are aggregated to the coarse layer. In addition, the research team proposes a number of residual codebooks descended from the original clusters. Then local descriptors assigned to the same cluster are distinguished by their residuals and divided into finer clusters. Through these codebooks, the difference vector between primary residual and its closest visual word in the residual codebooks is calculated and denoted as the secondary residual. By pooling them with the primary ones, the fine residuals with more discriminative information are obtained. Furthermore, the fine residuals are aggregated into one vector through the two-step aggregation, keeping the same dimension as the original.

22) Index Strategy for Image Retrieval

The research team propose cross indexing with grouplets, where the core idea is to view the database images as a set of grouplets, each of which is defined as a group of highly relevant images. Because a grouplet groups similar images together, the number of grouplets is smaller than the number of images, thus naturally leading to less memory cost. Moreover, the definition of a grouplet could be based on customized relations, allowing for seamless integration of advanced image features and data mining techniques like the deep convolutional neural network (DCNN) in off-line indexing. To validate the proposed framework, the research team constructs three different types of grouplets, which are respectively based on local similarity, regional relation, and global semantic modeling. Extensive experiments on public benchmark datasets demonstrate the efficiency and superior performance of the proposed approach. Moreover, the research team proposes a fast image retrieval framework to speed up the online retrieval process. To this end, an impact score for local features is proposed in the first place, which considers multiple properties of a local feature, including TF-IDF, scale, saliency, and ambiguity. Then, to decrease memory consumption, the impact score is quantized to an integer, which leads to a novel inverted index organization, called Q-Index. Importantly, based on the impact score, two closely complementary strategies are introduced: query pruning and early termination. On one hand, query pruning discards less important features in the query. On the other hand, early termination visits indexed features only with high impact scores, resulting in the partial traversing of the inverted index. The proposed approach is tested on two benchmark datasets populated with an additional 1 million images to account as negative examples. Compared with full traversal of the inverted index, it shows that the developed system is capable of visiting less than 10% of the “should-visit” postings, thus achieving a significant speed-up in query time while providing competitive retrieval accuracy.

23) Information Fusion for Image Retrieval

For vocabulary tree based image retrieval, the research team propose a semantic-aware co-indexing algorithm to jointly embed two strong cues into the inverted indexes: 1) local invariant features that are robust to delineate low-level image contents, and 2) semantic attributes from large-scale object recognition that may reveal image semantic meanings. For an initial set of inverted indexes of local features, the research team utilizes 1000 semantic attributes to filter out isolated images and insert semantically similar images to the initial set. Encoding these two distinct cues together effectively enhances the discriminative

capability of inverted indexes. Such co-indexing operations are totally off-line and introduce small computation overhead to online query cause only local features but no semantic attributes are used for query. Experiments and comparisons with recent retrieval methods on 3 datasets, i.e., UKbench, Holidays, Oxford5K, and 1.3 million images from Flickr as distractors, manifest the competitive performance of the proposed method. In addition, the research team propose a score-level fusion scheme based on a simple motivation: the score curve of a good feature is “L” shaped, while that of a bad feature is gradually dropping. In a nut-shell, the score curves are firstly normalized by reference curves trained on irrelevant data, which are expected to approximate the tails of the initial score curves. Then, feature effectiveness is estimated as negatively related to the area under the normalized score curve. In the proposed method, the offline operation is independent on the test database, making it well suited to dynamic systems. More importantly, the proposed method identifies “good” and “bad” features on-the-fly, and the results are competitive to the state-of-the-arts on three datasets.

24) Post Processing for Web Image Search

The research team propose a new attribute-assisted reranking method based on hypergraph learning. They first train several classifiers for all the pre-defined attributes and each image is represented by attribute feature consisting of the responses from these classifiers. Different from the existing methods, a hypergraph is then used to model the relationship between images by integrating low-level features and attribute features.

The research team also improve the hypergraph learning method approach presented in by adding a regularizer on the hyperedge weights which performs an implicit selection on the semantic attributes. This makes the proposed approach much more robust and discriminative for image representation as noisy attributes will be removed and informative ones will be selected. Comprehensive experiments have been conducted to empirically analyze the proposed method on more than 1,000 queries and 1 million images. The experimental results validate the effectiveness of the proposed method.

25) Action Recognition for Video Application

The research team propose a novel fine-grained action recognition pipeline by interaction part proposal and discriminative mid-level part mining. Firstly, a large number of candidate object regions are generated by using off-the-shelf object proposal tool, e. g., BING. Secondly, these object regions are matched and tracked across frames to form a large spatio-temporal graph based on the appearance matching and the dense motion trajectories through them. The research team then proposes an efficient approximate graph segmentation algorithm to partition and filter the graph into consistent local dense sub-graphs. These sub-graphs, which are spatiotemporal sub-volumes, represent the candidate interaction parts. Finally, the research team mines discriminative mid-level part detectors from the features computed over the candidate interaction parts. Extensive experiments have been conducted on human-object interaction datasets. The experimental results demonstrate that the proposed framework achieves consistent improvements over the state-of-the-art action recognition accuracies on the benchmarks, without using any object annotation. In addition, the research team proposes to use descriptors at Higher Semantic levels in combination with the low-level dynamic ones for action recognition.

26) Feature Quantization

The research team propose to construct a supporting visual word table for all visual words by visual word expansion. Given the initial quantization result, multiple approximate nearest visual words are identified by checking supporting visual word table, which benefits the retrieval recall. Moreover, a matching verification scheme based on binary SIFT (BSIFT) is presented. The L2-distance between original SIFT descriptors is demonstrated to be well kept with the metric of Hamming distance between the corresponding binary SIFT vectors. With the BSIFT verification, false positive matches can be effectively and efficiently identified and removed, which greatly improves the accuracy of large-scale image search. The proposed approach is evaluated by conducting partial-duplicate image search on a one-million image database. The experimental results demonstrate the effectiveness and efficiency of the proposed scheme.

27) Image Search Results Quality Assessment

The research team quantitatively study and formulate the image search result preference learning problem. A novel framework and a set of valuable features to automatically compare the quality of image search result lists are proposed. A general preference learning model and a query dependent preference learning model are proposed. The proposed approach has been tested on a variety of applications including optimal search engine selection, merging of search result lists, selecting the best visual feature and reranking approach for each individual query, and synonymous query suggestion. Extensive experimental results have demonstrated the effectiveness of the proposed approach and its promising applications on reranking feature and model selection, merging of image search results, as well as query suggestion. This work will explicitly guide the research in visual reranking ability estimation and provide a path for query difficulty modeling.

28) Image Search Reranking

The research team introduce a learning-based reranking method “Topic Aware Reranking” (TARerank) to refine text-based image search results. This method not only takes topic importance into consideration, but also directly learns a reranking model by optimizing a criterion related to reranking performance in terms of both relevance and diversity in one stage simultaneously. To better model the hierarchical topic structure of search results and describe the relevance and diversity in one criterion seamlessly, NCTC is also proposed to quantify the hierarchical TC. Compared with the two-step optimization in other diversified reranking methods, TARerank can achieve the joint optimum of improving relevance and diversity. Besides, the learning procedure can bridge the gap between low-level visual feature diversity and high-level semantic topic diversity to some extent. These two advantages ensure the superiority of TARerank. By conducting extensive experiments on a Web image dataset, the research team has demonstrated the effectiveness of the proposed method. This method will be a promising new paradigm for Web image search reranking.

29) Sketch-based 3D Model Retrieval

In this work, the research team propose and implement a novel 3D sketching virtual drawing “board” (software), which allows

users to freely draw 3D sketches in the air (a real 3D space). Based on this developed 3D sketching virtual drawing board, the first human 3D sketch dataset is collected. The research team also introduce a 3D sketch-based 3D model retrieval system to solve the matching problem between 3D sketches and models. And the proposed approach shows promising application potential for 3D sketch understanding or recognition, large scale 3D model search, and on-line 3D model shopping, etc. This work is the first attempt to explore 3D sketching in a 3D space and to develop an innovative retrieval system that enables users to search 3D models based on hand-drawn 3D sketches. The implications of this work could be tremendous, as 3D sketching allows for more direct communication in a user's drawing, which could not only enhance 3D model retrieval accuracy, but also provide a possibility for other human sketch related applications, such as virtual try-on systems for clothes, glasses and watches. This work will also explicitly guide the research in 3D sketching and provide a path for large scale sketch-based image, video, and object retrieval.

30) 3D Symmetry Detection
The research team propose a novel and efficient view-based symmetry detection algorithm. The proposed algorithm can find symmetry plane(s) by matching the viewpoint entropy features of a set of sample views of a 3D model aligned beforehand using Continuous Principal Component Analysis (CPCA). The experimental results show the proposed symmetry detection algorithm is more accurate (in terms of both the positions of detected symmetry planes and sensitivity to minor symmetry differences), efficient, robust (e.g. to the number of vertices and parameter settings such as view sampling), and versatile in finding symmetry planes of diverse models.

Award:
This project has resulted in the following¬¬ prestigious awards:
- Best Paper Award, the 4th ACM International Conference on Internet Multimedia Computing and Service (ICIMCS 2I012), September 2012.
- Best Paper Award, the IEEE International Conference on Multimedia and Expo (ICME) 2013.
- Best Paper Award, the Pacific-rim Conference on Multimedia (PCM), 2013.
- Best Paper Award, the 19th International Conference on Multimedia Modeling (MMM), January 2013.
- Best Paper Award, the ACM International Conference on Multimedia Retrieval (ICMR), June, 2015.
- Best Student Paper Candidate, the IEEE International Conference on Multimedia and Expo (ICME), July 28-July 2, 2015.

Honor and Recognition:
Faculty:
- Dr. Yijuan Lu (PI) was awarded Texas State University Junior Faculty Research Enhancement Award 2012.
- Dr. Yijuan Lu (PI) was nominated to Texas State University Presidential Award For Excellence In Scholarly/Creative Activities 2012.
- Dr. Qi Tian (co-PI) was promoted to Full Professor at UTSA, December 2012.
- Dr. Yijuan Lu (PI) and her team won the First Place in "Large Scale Sketch-Based 3D Shape Retrieval Competition", First Place in "Large-Scale Partial Shape Retrieval Using Simulated Range Images Competition", and Second Place in "Retrieval of Objects Captured with Low-Cost Depth-Sensing Cameras Competition" in EUROGRAPHICS 3D Shape Retrieval Contest 2013 (SHREC'13)
- Dr. Yijuan Lu (PI) is nominated to Texas State University Presidential Award For Excellence In Scholarly/Creative Activities 2013.
- Dr. Yijuan Lu (PI) received College Achievement Award for the Presidential Award for Excellence in Scholarly/Creative Activities, College of Science and Engineering, Texas State University, 2014.
- Dr. Qi Tian (co-PI) received Research Achievement Award, College of Science, UTSA, December 2014.
- Dr. Yijuan Lu (PI) received Presidential Distinction Award for Excellence in Service, Texas State University, 2015.
- Dr. Yijuan Lu (PI) and her team won the First Place in "3D Sketch-Based 3D Shape Retrieval Competition" in EUROGRAPHICS 3D Shape Retrieval Contest 2016 (SHREC'16).
- Dr. Qi Tian (co-PI) is elevated to IEEE Fellow (class 2016), November 2015.

Student:
- Shaomin Fang received Excellence in Graduate Research Award at Texas State University 2013.
- Yuxiang Ye received Excellence in Graduate Research Award at Texas State University 2014, 2015.
- Junjie Cai received ACM Multimedia Student Travel Award 2014.
- Junjie Cai received UTSA Graduate Student Professional Development Award 2014.

4. Publications:

Under this project, the research team have published 49 top-tiered journal papers including IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI), IEEE Transactions on Multimedia (TMM), IEEE Transactions on Circuits and Systems for Video Technology (TCSVT), ACM Transactions on Knowledge Discovery from Data (TKDD), etc., and 62 peer-reviewed conference papers including IEEE CVPR, ACM Multimedia, ICCV, etc. The complete list of the published peer-reviewed journal and conference papers under this project are listed as follows.
Journal Papers

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Technology Transfer

Final Report Attachment

Project Title: Large-Scale Partial-Duplicate Image Retrieval and Its Applications

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1. Foreword

This project started in January 2012 and ended in January 2016 with one year no-cost extension from January 2015 to January 2016. There are three Post-docs (Xinmei Tian, Wengang Zhou, Bo Li), four Ph.D. students (Jie Xiao, 2008-2014, Xia Li, 2008-2014, Junjie Cai, 2011-2015, Yang Zhou, 2015), three master students (Shaomin Fang, 2012-2013, Travis Bulgerin, 2013-2014, Yuxiang Ye, 2014-2016), and two undergraduate students (Daniel Brooks, Robert Dunk) supported by this ARO grant. Xinmei Tian and Wengang Zhou joined CS Department of University of Science and Technology of China as tenure-track assistant professors. Bo Li joined Department of Mathematics and Computer Science in University of Central Missouri as an assistant professor in 2015. Xia Li joined in Google in 2014 as a Software Development Engineer (SDE). Jie Xiao joined in Rocket Fuel Inc. as a Research Scientist in 2014. Junjie Cai joined in Blippar Inc. as a Research Scientist in 2015. Shaomin Fang joined in Emerson at Austin in 2013 and Yuxiang Ye will graduate in May 2016 and will join in Google June 2016. The project has been finished successfully within the timeline and all the research goals proposed in the original proposal have been achieved.

During the project period, the PI Dr. Lu was promoted to Associate Professor at Texas State. Dr. Tian was promoted to Full Professor at UTSA and was elevated to IEEE Fellow (class 2016). The PIs sincerely thank for ARO and the program manager Dr. Liyi Dai for supporting this research during the past 4 years. Without the dedicated support from Dr. Dai and ARO, this project won't be done successfully. We look forwards to the future research collaboration with Dr. Dai and ARO.

2. Statement of the problem studied

The explosive growth of Internet Media (partial-duplicate/similar images, 3D objects, 3D models, etc.) sheds bright light on many promising applications in forensics, surveillance, 3D animation, mobile visual search, and 3D model/object search. Compared with the general images, partial-duplicate images have some intrinsic properties such as high repeatability of local features, consistent local patch appearance, and stable spatial configuration. Compared with the general

2D objects, 3D models/objects consist of 3D data information (typically a list of vertices and faces) to represent 3D objects. However, these unique properties of partial-duplicate images and 3D models have not been well exploited to design effective and efficient search algorithms. Because of this, existing works for large-scale partial-duplicate image retrieval and 3D model retrieval suffer from two major problems: **low accuracy** and **low efficiency**. These problems make them fall far below many applications' requirement. This project has investigated many key problems in large-scale partial-duplicate/similar image and 3D model retrieval: feature descriptor problem, image representation problem, index strategy problem, feature quantization problem, image search results quality assessment problem, image search reranking problem, sketch-based 3D model retrieval problem, and related search problems and has proposed a series of effective and efficient approaches to solve them.

3. Summary of the scientific accomplishments

The key elements developed in this project will make significant contributions to improve the performance of large scale partial duplicate image retrieval system, large scale 3D model retrieval system, and personalized image retrieval. The research teams are one of the first (to their best knowledge) in the field who

- propose a novel strategy to generate a reliable, easily updated visual dictionary with low computational cost. In our method, no visual codebook is needed to be trained and the quantizer is independent of collections of images;
- propose to formulate the codebook construction and contextual subspace learning into one optimization problem and embed semantic information;
- apply visual word expansion approach to reduce the feature quantization error and boost the retrieval recall;
- propose to embed the spatial information between local features into the inverted index file efficiently;
- propose to build geometric square coding and geometric fan coding together to fully capture the global geometric context of local features in an image and effectively discover false feature matches between images.
- propose a novel flexible scale invariant feature transform (SIFT) binarization (FSB) algorithm;
- propose to explore the use of partial binary descriptors as direct codebook indices (addresses);
- introduce a novel IDF family by the use of Lp-norm pooling technique;
- propose a novel attribute-assisted retrieval model for reranking images;
- build the largest comprehensive 3D shape database that contains different types of models including generic, articulated, CAD and architecture models;
- construct the largest sketch-3D model benchmark that contains a large number of diverse types of sketches and models;
- apply, compare, and analyze state-of-the-art 3D model retrieval approaches on the collected sketch and 3D model benchmark;

- propose a simple and efficient view-based 3D symmetry detection method.
- propose a novel matching verification scheme based on binary SIFT (BSIFT);
- propose two novel binary feature descriptors: COGE and Edge-SIFT and investigate representing the spatial context of local features into binary codes;
- encode local invariant features and high level semantic attributes together to effectively enhance the discriminative capability of inverted indexes;
- use the semantic classification information to reduce the semantic gap, as well as to adequately utilize the better-performing global feature matching to improve sketch-based 3D model retrieval efficiency;
- propose a 3D visual complexity metric based on the viewpoint entropy distribution of a set of sample views;
- explore the correlations between users' different touch behaviors and human attention, investigate their contribution to the human eye fixation, and propose a novel supervised learning approach to learn good image saliency maps from multiple touch behaviors.

During the past year (2012), the following scientific accomplishments have been made:

1) Scalar Quantization

The research team investigate bit vector quantization algorithms to address the "high computational cost", "limited reliability", and "update inefficiency" problems in the codebook generation stage. A novel feature quantization algorithm, *scalar quantization*, is proposed. With scalar quantization, a local feature is quantized to a descriptive and discriminative bit-vector, of which the first tens of bits are taken out as *code word*. Our quantizer is independent of collections of images. In addition, the result of scalar quantization naturally lends itself to adapt to the classic inverted file structure for image indexing. Moreover, the quantization error can be flexibly reduced and controlled by efficiently enumerating nearest neighbors of code words.

2) Discriminative Codebook Learning

The research team propose a novel supervised discriminative codebook learning method, which can find a contextual subspace to embed the semantic information into codebook generation and learn a contextual subspace and discriminative codebook simultaneously. In the learned new space, images from different classes can be well separated and images from the same class are close to each other. The research team applied the proposed method on Web image search re-ranking problem and the experimental results on two real Web image search datasets have demonstrated the effectiveness of our approach and its superiority than other state-of-the-art codebook learning methods.

3) Visual Word Expansion and Binary SIFT

The research team propose a novel visual word expansion approach to improve the feature quantization accuracy and boost the retrieval recall. The proposed visual word expansion scheme is based on the observation that the expected nearest visual word to a test feature is always close to the approximate nearest visual word, which can be efficiently identified by the hierarchical *k*-

NN search. Experiments on image search in million-scale dataset demonstrate the effectiveness of the proposed visual word expansion approach.

Moreover, the research team design a new scheme to transform a SIFT descriptor to a binary bit stream, called binary SIFT. Extensive study with large-scale (trillion) samples reveal that the generated binary SIFT effectively keeps the distance metric of the original SIFT descriptor.

4) Embedding Spatial Context into Inverted File

The research team explore two novel ways to embed the spatial information between local features into the inverted index file. A one-one relationship approach is proposed to record feature tuples into the inverted file, which consist of a pair of single features and their corresponding spatial relationship. A one-multiple relationship approach is proposed to record the spatial relationship between a single feature and its surrounding features, which are clustered into different groups based on their locations. With the embedded spatial information in the inverted index file, feature matching with geometric verification can be performed implicitly, efficiently, and effectively in the inverted file traversing step, which make the proposed methods more suitable for large-scale image search.

5) Spatial and Geometric Coding for Geometric Verification

The research team investigate two different coding algorithms "Spatial Coding" and "Geometric Coding" to achieve fast and accurate geometric verification of local features in the post processing step. The proposed spatial coding algorithm encodes the relative positions between each pair of features along the horizontal (*X*-axis) and vertical (*Y*-axis) direction by generating two binary spatial maps *X*-map and *Y*-map. The proposed geometric coding method consists of geometric square coding and geometric fan coding, which describe the spatial relationships of local features (e.g. inside or outside of geometric square and fan) into *H*-map, *V*-map, and *S*-map for global verification to remove geometrically inconsistent feature matches. These two approaches are not only computationally efficient, but also effective in detecting partial-duplicate images with rotation, scale changes, partial-occlusion, and background clutter.

6) Applications

During the exploration of solutions to solve the above scientific barriers in the partial duplicate image retrieval, the research team find some other interesting applications, which may share similar problems, such as license plate detection (characters in different license plates are duplicates of each other), similar song retrieval, and 3D image search. Motivated by these similarities, several new approaches are proposed for these applications by bringing the ideas in the partial duplication image retrieval.

Observing that characters in different license plates are duplicates of each other, we bring in the idea of bag-of-words (BoW) model popularly into license plate detection. The research team propose a novel scheme to automatically locate license plate by principal visual word discovery and local feature matching. For large scale similar song retrieval, the research team proposed to utilize beat-aligned chroma patches and applied location coding scheme to encode the location

relationships among beat-aligned chroma patches in a song. Our approach is both efficient and effective to discover true matches of beat chroma patches between songs with low computational cost. In the 3D image retrieval, the research team propose a sketch-based 3D model retrieval algorithm by utilizing viewpoint entropy-based adaptive view clustering and shape context matching. The algorithm is tested on a latest sketch-based 3D model retrieval benchmark and the results demonstrate the superior performances and advantages of our algorithm.

During the past year (2013), the following scientific accomplishments have been made:

7) Feature Quantization

The research team propose to construct a supporting visual word table for all visual words by visual word expansion. Given the initial quantization result, multiple approximate nearest visual words are identified by checking supporting visual word table, which benefits the retrieval recall. Moreover, a matching verification scheme based on binary SIFT (BSIFT) is presented. The L_2-distance between original SIFT descriptors is demonstrated to be well kept with the metric of Hamming distance betThe research teamen the corresponding binary SIFT vectors. With the BSIFT verification, false positive matches can be effectively and efficiently identified and removed, which greatly improves the accuracy of large-scale image search. The proposed approach is evaluated by conducting partial-duplicate image search on a one-million image database. The experimental results demonstrate the effectiveness and efficiency of the proposed scheme.

8) Binary Feature Descriptors for Image Retrieval

The research team propose two novel binary feature descriptors: COGE and Edge-SIFT. The proposed COGE exploits the anisotropy and the non-uniformity of the underlying gradient distributions. Therefore, it exhibits better results than state-of-the-art methods with respect to distinctiveness, robustness, and storage cost. The proposed Edge-SIFT is generated from the binary edge maps of scale and orientation-normalized image patches. By preserving both locations and orientations of edges and compressing the sparse binary edge maps with a boosting strategy, Edge-SIFT shows strong discriminative power with compact representation.

In addition, the research team investigate representing the spatial context of local features into binary codes to implicitly achieve geometric verification by efficient comparison of the binary codes. Moreover, a weighted Hamming distance ranking algorithm (WhRank) to rank the binary codes of hashing methods is developed. By assigning different bit-level weights to different hash bits, the returned binary codes are ranked at a finer-grained binary code level. Experiments on several state-of-the-art benchmark data sets with million-scale distractor images demonstrate the effectiveness of the proposed algorithms.

9) Semantic-aware Co-indexing for Image Search

The research team propose a novel approach for embedding semantic attributes into the pipeline of image search. Inverted indexes in image retrieval not only allow fast access to database images but also summarize all knowledge about the database, so that their discriminative

capacity largely determines the retrieval performance. For vocabulary tree based image retrieval, a semantic-aware co-indexing algorithm is proposed to jointly embed two strong cues into the inverted indexes: 1) local invariant features that are robust to delineate low-level image contents, and 2) semantic attributes from large-scale object recognition that may reveal image semantic meanings. Encoding these two distinct cues together effectively enhances the discriminative capability of inverted indexes. Such co-indexing operations are totally off-line, and therefore introduce small computation overhead to online query. Experiments and comparisons with recent retrieval methods have evidently demonstrated the significant improvement in retrieval performance and efficiency.

10) Sketch-based Image/3D Model Retrieval

The research team propose a new sketch feature to capture both the local and global information of a sketch. The proposed sketch feature can handle the rotation of sketches better by further integrating a set of rotation-invariant global features for a sketch. In addition, an intelligent sketch recognizer through supervised learning is developed to correctly capture the semantic meanings of users' sketches. The research team also conducts a comprehensive study of the semantic gap between user sketches and 3D models and proposes a novel semantic sketch-based 3D model search algorithm to bridge such a semantic gap. The experimental results confirmed that the proposed sketch recognizer is more robust to sketch rotation and can describe user sketches well. In addition, the proposed semantic retrieval approach significantly improves the retrieval accuracy and reduces the search time over other state-of-the-art sketch-based 3D model retrieval algorithms. It further validated that the proposed approach could bridge the semantic gap between the diverse query sketches and 3D models effectively.

11) **Large Scale 3D Model Retrieval**

The research team propose a new 3D model retrieval algorithm by adaptive view clustering. A novel 3D visual complexity metric is formulated based on the viewpoint entropy distribution of a set of uniformly sampled views of the 3D model. Then, it guides adaptive view clustering of a 3D model to shortlist a set of representative sample views for 2D-3D comparison, which largely reduces the number of sample views for comparison and therefore greatly improves the computational efficiency. After that, a shape context matching algorithm is used for the 2D-3D matching between the query and the representative views for each model. Experimental results on several latest benchmarks have evidently demonstrated our significant improvement in retrieval performance and efficiency.

In addition, the research team organize a "Large Scale Sketch-based 3D Model Retrieval" competition in the Shape Retrieval Contest (SHREC) 2013, which is held at the 3D Object Retrieval (3DOR) workshop of Eurographics 2013. In the meantime, the research team also attend two SHREC contests on "Large-Scale 3D Partial Shape Retrieval Track Using Simulated Range Images" and "Retrieval of 3D Objects Captured with Low-Cost Depth-Sensing Cameras". In these competitions, the proposed 3D model retrieval algorithm receives **First Place** in the

large-scale sketch-based 3D retrieval track, **First Place** in the range scan track, and obtains **Second Place** in the low-cost depth-sensing camera track.

12) Touch-based Personalized Image Search

The research team quantitatively studied and analyzed human attention from a variety of touch behaviors, and proposes a set of valuable features from the touch information. A series of experiments are designed and conducted with the conventional eye-fixation based saliency serving as the ground truth. An image browsing app is designed on a touch mobile phone to collect users' touch behavior data. In addition, a novel touch saliency learning approach is proposed to automatically learn the correlation between different touch behaviors and human eye fixations, and then to derive a good image saliency map from a variety of touch behaviors. During the process of building a supervised learning model, the weights of different human touch behaviors are learned, which indicate the different contributions of these behaviors to the user's attention information. The experimental results have demonstrated the validity of the study and the potential and effectiveness of the proposed approach.

13) Applications

In addition, the research team explored many important related problems: 1) "human movement summarization and depiction from videos" problem. Previous action summarization methods all rely on 3D motion capture or manually labeled data, without which depicting actions is a challenging task. A novel scheme is proposed to automatically summarize and depict human movements from 2D videos without 3D motion capture or manually labeled data. The proposed method can successfully segment videos into sub-actions with an effective streamline matching scheme, track points on body parts, and depict the human articulated motion with arrows and motion particles. 2) "image matching" problem. A new matching method, Semantic-Spatial Matching (SSM) is proposed. SSM conducts region matching by considering both the spatial layout and the semantic content information. SSM has the advantage not only being robust to rotation, flipping and other variances, but also simple and easy for implementation. Experiments on two benchmark datasets demonstrate its effectiveness in object and scene classifications. 3) "3D scene reconstruction" problem. The performance of the PMVS (Patch-based Multi-View Stereo software) for scene reconstruction from stereo pairs of scenes captured by a simple 3D camera has been analyzed. A Canny feature-based PMVS algorithm and a preliminary disparity map-based stereo reconstruction algorithm are proposed. Both proposed approaches are promising for related applications which require effective 3D scene reconstruction from a set of sparsely sampled pairs. 4) "image annotation" problem. An automatic image annotation approach using semantic relevance is proposed. It constructs an improved probabilistic model to characterize different regions' contributions to the semantics more accurately based on the spatial，visual and contextual information of the region. And it also helps expand the coverage of the semantic concept with semantic relevance information.

During the past year (2014), the following scientific accomplishments have been made:

14) Compact Binary Feature Descriptors for Image Retrieval

The research team propose a novel flexible scale invariant feature transform (SIFT) binarization (FSB) algorithm for large-scale image search. The FSB algorithm explores the magnitude patterns of SIFT descriptor. It is unsupervised and the generated binary codes are demonstrated to be dispreserving. Besides, a new searching strategy is investigated to find target features based on the cross-indexing in the binary SIFT space and original SIFT space. The experiments on large-scale partial duplicate image retrieval system demonstrate the effectiveness and efficiency of the proposed algorithm.

In addition, the research team explored the use of partial binary descriptors as direct codebook indices (addresses). Typically, binary descriptors are clustered into codewords and quantized with Hamming distance, following the conventional bag-of-words strategy. However, such codewords formulated in Hamming space do not present obvious indexing and search performance improvement as compared to the Euclidean codewords. Without explicit codeword construction, the proposed approach performs to build multiple index tables which concurrently check for collision of the same hash values. The evaluation is performed on two public image datasets and the experimental results demonstrate the indexing efficiency and retrieval accuracy of our approach.

15) TF-IDF strategy for Image Retrieval

The research team introduced a novel IDF family by the use of Lp-norm pooling technique. Carefully designed, the proposed IDF considers the term frequency, document frequency, the complexity of images, as well as the codebook information. The research team further proposes a parameter tuning strategy, which helps to produce optimal balancing between TF and pIDF weights, yielding the so-called Lp-norm IDF (pIDF). Further, by counting for the term-frequency in each image, the proposed pIDF helps to alleviate the visual word burstiness phenomenon.

Moreover, the team initializes to embed multiple binary features at indexing level. To model correlation between features, a multi-IDF scheme is introduced, through which different binary features are coupled into the inverted file. As an extension, the research team also explores the fusion of binary color feature into image retrieval. The joint integration of the SIFT visual word and binary features greatly enhances the precision of visual matching, reducing the impact of false positive matches.

16) An attribute-assisted Reranking Model for Web Image Search

The research team proposed a novel attribute-assisted retrieval model for reranking images. Based on the classifiers for all the predefined attributes, each image is represented by an attribute feature consisting of the responses from these classifiers. A hypergraph is used to model the relationship between images by integrating low-level visual features and semantic attribute features. And hypergraph ranking is applied to re-order the images. Its basic principle is that visually similar images should have similar ranking scores. A visual-attribute joint hypergraph learning approach has been proposed to simultaneously explore two information sources. The extensive experiments have been conducted on 1,000 queries in MSRA-MM V2.0 dataset. The

experimental results demonstrate the effectiveness of the proposed attribute-assisted Web image search reranking method.

17) **Large Scale Comprehensive 3D Model Retrieval**

The research team built a Large Scale Comprehensive 3D model Benchmark dataset (**SHREC14LSGTB**). This 3D shape dataset contains 8,987 models in a variety of types (generic, articulated, CAD and architecture models) and classified into 171 categories. This work is the first work to integrate existing 3D model datasets to form a new, larger benchmark corpus for comprehensive 3D shape retrieval. The newly created benchmark is the most extensive to date in terms of the number of semantic query categories covered as well as the variations of model types. In particular, it combines generic and domain dependent model types and therefore rates the retrieval performance with respect to cross-domain retrieval tasks.

18) Sketch-based 3D Model Retrieval

The research team built the largest sketch-3D model benchmark dataset. The benchmark contains 13,680 sketches and 8,987 3D models, divided into 171 distinct classes. The developed benchmark is the most extensive to date in terms of the number of semantic query categories covered as well as the variations of model types. The benchmark supports both sketch and 3D model queries, thus providing a unified platform to test diverse 3D model retrieval algorithms belonging to either Query-by-Model or Query-by-Sketch 3D retrieval techniques. This benchmark also provides an important resource for the community of sketch-based 3D retrieval and will foster the development of practical sketch based 3D retrieval applications.

Based on this new developed benchmark, the research team organized a sketch-based 3D model retrieval contest in 2014 Eurographics. The task of the contest is to evaluate the performance of different sketch-based 3D model retrieval algorithms using a large scale hand-drawn sketch query dataset on a comprehensive 3D model dataset. 12 runs of 6 methods have been submitted by 4 groups. The research team performs a comprehensive comparison study and evaluates current state-of-the-art sketch-based retrieval approaches, especially in terms of scalability using 7 popular performance metrics. This benchmark and comprehensive study will provide important guidance on future research directions of this research area.

19) 3D Symmetry Detection

The research team proposed a novel and efficient view-based symmetry detection algorithm. The proposed algorithm can find symmetry plane(s) by matching the viewpoint entropy features of a set of sample views of a 3D model aligned beforehand using Continuous Principal Component Analysis (CPCA). The experimental results show the proposed symmetry detection algorithm is more accurate (in terms of both the positions of detected symmetry planes and sensitivity to minor symmetry differences), efficient, robust (e.g. to the number of vertices and parameter settings such as view sampling), and versatile in finding symmetry planes of diverse models.

During the past year (2015), the following scientific accomplishments have been made:

20) Feature Descriptors for Large-scale Image Retrieval

The research team propose a novel cascaded scalar quantization scheme in dual resolution. They formulate the visual feature matching as a range-based neighbor search problem and approach it by identifying hyper-cubes with a dual-resolution scalar quantization strategy. Specifically, for each dimension of the dimension-reduced feature, scalar quantization is performed at both coarse and fine resolutions. The scalar quantization results at the coarse resolution are cascaded over multiple dimensions to index an image database. The scalar quantization results over multiple dimensions at the fine resolution are concatenated into a binary super-vector and stored into the index list for efficient verification. The proposed cascaded scalar quantization (CSQ) method is free of the costly visual codebook training and thus is independent of any image descriptor training set. The index structure of the CSQ is flexible enough to accommodate new image features and scalable to index large-scale image database.

The research teams also extend the concept of image retargeting and propose a new image resizing approach that is devoted to preserving the robust local features in the query image while resizing it. Based on the extended concept, a novel mobile-visual-search scheme is introduced to conduct the proposed approach to reduce the size of the query image for achieving low bit-rate visual search. Extensive experiments show that the proposed approach obtains superior retrieval performance than state-of-the-art image resizing approaches at the similar query size; meanwhile, it is cost effective in terms of processing time.

21) Image Representation for Large-scale Image Retrieval

The research team propose a hierarchical method to construct VLAD descriptor (HVLAD) to inherit the benefit of finer division bringing by larger vocabulary while preserving the same dimension with the original VLAD descriptor. In the proposed HVLAD descriptor, by generating sub-words to each words of the coarse vocabulary that is adopted to build original VLAD descriptor, a hidden layer visual vocabulary is constructed. With the hidden layer vocabulary, the feature space is finely divided. The residual vectors between local features and sub-words are first aggregated at the hidden layer and then are aggregated to the coarse layer. In addition, the research team proposes a number of residual codebooks descended from the original clusters. Then local descriptors assigned to the same cluster are distinguished by their residuals and divided into finer clusters. Through these codebooks, the difference vector between primary residual and its closest visual word in the residual codebooks is calculated and denoted as the secondary residual. By pooling them with the primary ones, the fine residuals with more discriminative information are obtained. Furthermore, the fine residuals are aggregated into one vector through the two-step aggregation, keeping the same dimension as the original.

22) Index Strategy for Image Retrieval

The research team propose cross indexing with grouplets, where the core idea is to view the database images as a set of grouplets, each of which is defined as a group of highly relevant images. Because a grouplet groups similar images together, the number of grouplets is smaller than the number of images, thus naturally leading to less memory cost. Moreover, the definition

of a grouplet could be based on customized relations, allowing for seamless integration of advanced image features and data mining techniques like the deep convolutional neural network (DCNN) in off-line indexing. To validate the proposed framework, the research team constructs three different types of grouplets, which are respectively based on local similarity, regional relation, and global semantic modeling. Extensive experiments on public benchmark datasets demonstrate the efficiency and superior performance of the proposed approach. Moreover, the research team proposes a fast image retrieval framework to speed up the online retrieval process. To this end, an impact score for local features is proposed in the first place, which considers multiple properties of a local feature, including TF-IDF, scale, saliency, and ambiguity. Then, to decrease memory consumption, the impact score is quantized to an integer, which leads to a novel inverted index organization, called Q-Index. Importantly, based on the impact score, two closely complementary strategies are introduced: query pruning and early termination. On one hand, query pruning discards less important features in the query. On the other hand, early termination visits indexed features only with high impact scores, resulting in the partial traversing of the inverted index. The proposed approach is tested on two benchmark datasets populated with an additional 1 million images to account as negative examples. Compared with full traversal of the inverted index, it shows that the developed system is capable of visiting less than 10% of the "should-visit" postings, thus achieving a significant speed-up in query time while providing competitive retrieval accuracy.

23) Information Fusion for Image Retrieval

For vocabulary tree based image retrieval, the research team propose a semantic-aware co-indexing algorithm to jointly embed two strong cues into the inverted indexes: 1) local invariant features that are robust to delineate low-level image contents, and 2) semantic attributes from large-scale object recognition that may reveal image semantic meanings. For an initial set of inverted indexes of local features, the research team utilizes 1000 semantic attributes to filter out isolated images and insert semantically similar images to the initial set. Encoding these two distinct cues together effectively enhances the discriminative capability of inverted indexes. Such co-indexing operations are totally off-line and introduce small computation overhead to online query cause only local features but no semantic attributes are used for query. Experiments and comparisons with recent retrieval methods on 3 datasets, i.e., UKbench, Holidays, Oxford5K, and 1.3 million images from Flickr as distractors, manifest the competitive performance of the proposed method. In addition, the research team propose a score-level fusion scheme based on a simple motivation: the score curve of a good feature is "L" shaped, while that of a bad feature is gradually dropping. In a nut-shell, the score curves are firstly normalized by reference curves trained on irrelevant data, which are expected to approximate the tails of the initial score curves. Then, feature effectiveness is estimated as negatively related to the area under the normalized score curve. In the proposed method, the offline operation is independent on the test database, making it well suited to dynamic systems. More importantly, the proposed method identifies "good" and "bad" features on-the-fly, and the results are competitive to the state-of-the-arts on three datasets.

24) Post Processing for Web Image Search

The research team propose a new attribute-assisted reranking method based on hypergraph learning. They first train several classifiers for all the pre-defined attributes and each image is represented by attribute feature consisting of the responses from these classifiers. Different from the existing methods, a hypergraph is then used to model the relationship between images by integrating low-level features and attribute features.

The research team also improve the hypergraph learning method approach presented in by adding a regularizer on the hyperedge weights which performs an implicit selection on the semantic attributes. This makes the proposed approach much more robust and discriminative for image representation as noisy attributes will be removed and informative ones will be selected. Comprehensive experiments have been conducted to empirically analyze the proposed method on more than 1,000 queries and 1 million images. The experimental results validate the effectiveness of the proposed method.

25) Action Recognition for Video Application

The research team propose a novel fine-grained action recognition pipeline by interaction part proposal and discriminative mid-level part mining. Firstly, a large number of candidate object regions are generated by using off-the-shelf object proposal tool, e.g., BING. Secondly, these object regions are matched and tracked across frames to form a large spatio-temporal graph based on the appearance matching and the dense motion trajectories through them. The research team then proposes an efficient approximate graph segmentation algorithm to partition and filter the graph into consistent local dense sub-graphs. These sub-graphs, which are spatiotemporal sub-volumes, represent the candidate interaction parts. Finally, the research team mines discriminative mid-level part detectors from the features computed over the candidate interaction parts. Extensive experiments have been conducted on human-object interaction datasets. The experimental results demonstrate that the proposed framework achieves consistent improvements over the state-of-the-art action recognition accuracies on the benchmarks, without using any object annotation. In addition, the research team proposes to use descriptors at Higher Semantic levels in combination with the low-level dynamic ones for action recognition.

26) Feature Quantization

The research team propose to construct a supporting visual word table for all visual words by visual word expansion. Given the initial quantization result, multiple approximate nearest visual words are identified by checking supporting visual word table, which benefits the retrieval recall. Moreover, a matching verification scheme based on binary SIFT (BSIFT) is presented. The L_2-distance between original SIFT descriptors is demonstrated to be well kept with the metric of Hamming distance between the corresponding binary SIFT vectors. With the BSIFT verification, false positive matches can be effectively and efficiently identified and removed, which greatly improves the accuracy of large-scale image search. The proposed approach is evaluated by conducting partial-duplicate image search on a one-million image database. The experimental results demonstrate the effectiveness and efficiency of the proposed scheme.

27) Image Search Results Quality Assessment

The research team quantitatively study and formulate the image search result preference learning problem. A novel framework and a set of valuable features to automatically compare the quality of image search result lists are proposed. A general preference learning model and a query dependent preference learning model are proposed. The proposed approach has been tested on a variety of applications including optimal search engine selection, merging of search result lists, selecting the best visual feature and reranking approach for each individual query, and synonymous query suggestion. Extensive experimental results have demonstrated the effectiveness of the proposed approach and its promising applications on reranking feature and model selection, merging of image search results, as well as query suggestion. This work will explicitly guide the research in visual reranking ability estimation and provide a path for query difficulty modeling.

28) Image Search Reranking

The research team introduce a learning-based reranking method "Topic Aware Reranking" (TARerank) to refine text-based image search results. This method not only takes topic importance into consideration, but also directly learns a reranking model by optimizing a criterion related to reranking performance in terms of both relevance and diversity in one stage simultaneously. To better model the hierarchical topic structure of search results and describe the relevance and diversity in one criterion seamlessly, NCTC is also proposed to quantify the hierarchical TC. Compared with the two-step optimization in other diversified reranking methods, TARerank can achieve the joint optimum of improving relevance and diversity. Besides, the learning procedure can bridge the gap between low-level visual feature diversity and high-level semantic topic diversity to some extent. These two advantages ensure the superiority of TARerank. By conducting extensive experiments on a Web image dataset, the research team has demonstrated the effectiveness of the proposed method. This method will be a promising new paradigm for Web image search reranking.

29) Sketch-based 3D Model Retrieval

In this work, the research team propose and implement a novel 3D sketching virtual drawing "board" (software), which allows users to freely draw 3D sketches in the air (a real 3D space). Based on this developed 3D sketching virtual drawing board, the first human 3D sketch dataset is collected. The research team also introduce a 3D sketch-based 3D model retrieval system to solve the matching problem between 3D sketches and models. And the proposed approach shows promising application potential for 3D sketch understanding or recognition, large scale 3D model search, and on-line 3D model shopping, etc.

This work is the first attempt to explore 3D sketching in a 3D space and to develop an innovative retrieval system that enables users to search 3D models based on hand-drawn 3D sketches. The implications of this work could be tremendous, as 3D sketching allows for more direct communication in a user's drawing, which could not only enhance 3D model retrieval accuracy,

but also provide a possibility for other human sketch related applications, such as virtual try-on systems for clothes, glasses and watches. This work will also explicitly guide the research in 3D sketching and provide a path for large scale sketch-based image, video, and object retrieval.

30) 3D Symmetry Detection

The research team propose a novel and efficient view-based symmetry detection algorithm. The proposed algorithm can find symmetry plane(s) by matching the viewpoint entropy features of a set of sample views of a 3D model aligned beforehand using Continuous Principal Component Analysis (CPCA). The experimental results show the proposed symmetry detection algorithm is more accurate (in terms of both the positions of detected symmetry planes and sensitivity to minor symmetry differences), efficient, robust (e.g. to the number of vertices and parameter settings such as view sampling), and versatile in finding symmetry planes of diverse models.

Award:

This project has resulted in the following prestigious awards:

- **Best Paper Award**, the 4th ACM International Conference on Internet Multimedia Computing and Service (ICIMCS 2I012), September 2012.
- **Best Paper Award**, the IEEE International Conference on Multimedia and Expo (ICME) 2013.
- **Best Paper Award**, the Pacific-rim Conference on Multimedia (PCM), 2013.
- **Best Paper Award**, the 19th International Conference on Multimedia Modeling (MMM), January 2013.
- **Best Paper Award**, the ACM International Conference on Multimedia Retrieval (ICMR), June, 2015.
- **Best Student Paper Candidate**, the IEEE International Conference on Multimedia and Expo (ICME), July 28-July 2, 2015.

Honor and Recognition:

Faculty:

- Dr. Yijuan Lu (PI) was awarded Texas State University **Junior Faculty Research Enhancement Award** 2012.
- Dr. Yijuan Lu (PI) was nominated to Texas State University **Presidential Award For Excellence In Scholarly/Creative Activities** 2012.
- Dr. Qi Tian (co-PI) was promoted to **Full Professor** at UTSA, December 2012.
- Dr. Yijuan Lu (PI) and her team won the **First Place** in “Large Scale Sketch-Based 3D Shape Retrieval Competition”, **First Place** in “Large-Scale Partial Shape Retrieval Using Simulated Range Images Competition”, and **Second Place** in “Retrieval of Objects

Captured with Low-Cost Depth-Sensing Cameras Competition" in EUROGRAPHICS 3D Shape Retrieval Contest 2013 (SHREC'13)

- Dr. Yijuan Lu (PI) is nominated to Texas State University **Presidential Award For Excellence In Scholarly/Creative Activities** 2013.
- Dr. Yijuan Lu (PI) received **College Achievement Award** for the Presidential Award for Excellence in Scholarly/Creative Activities, College of Science and Engineering, Texas State University, 2014.
- Dr. Qi Tian (co-PI) received **Research Achievement Award**, College of Science, UTSA, December 2014.
- Dr. Yijuan Lu (PI) received **Presidential Distinction Award** for Excellence in Service, Texas State University, 2015.
- Dr. Yijuan Lu (PI) and her team won the **First Place** in "3D Sketch-Based 3D Shape Retrieval Competition" in EUROGRAPHICS 3D Shape Retrieval Contest 2016 (SHREC'16).
- Dr. Qi Tian (co-PI) is elevated to **IEEE Fellow** (class 2016), November 2015.

Student:

- Shaomin Fang received **Excellence in Graduate Research Award** at Texas State University 2013.
- Yuxiang Ye received **Excellence in Graduate Research Award** at Texas State University 2014, 2015.
- Junjie Cai received **ACM Multimedia Student Travel Award** 2014.
- Junjie Cai received **UTSA Graduate Student Professional Development Award** 2014.

4. Publications:

Under this project, the research team have published 49 top-tiered journal papers including *IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI)*, *IEEE Transactions on Multimedia (TMM)*, *IEEE Transactions on Circuits and Systems for Video Technology (TCSVT)*, *ACM Transactions on Knowledge Discovery from Data (TKDD)*, etc., and 62 peer-reviewed conference papers including IEEE CVPR, ACM Multimedia, ICCV, etc. The complete list of the published peer-reviewed journal and conference papers under this project are listed as follows.

Journal Papers

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